# Suppression of high Pt hadrons at mid-rapidity in central heavy ions collisions from PHENIX

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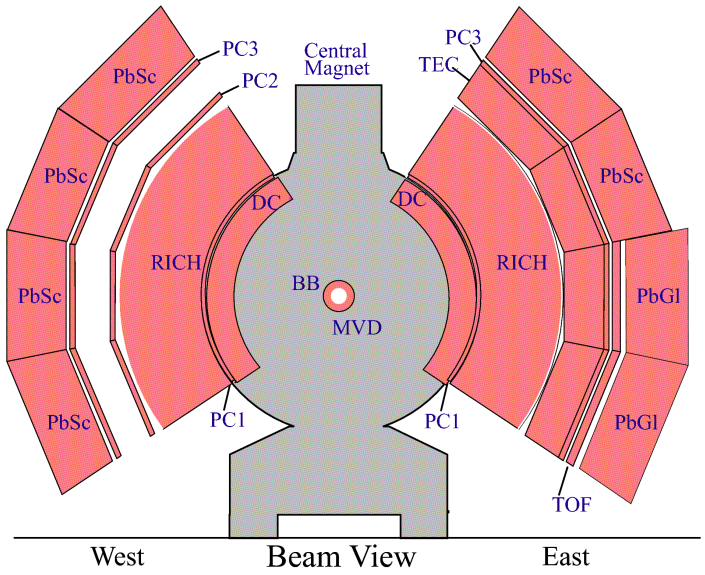
# PHENIX setup and resolutions for Drift Chamber, TOF and Electromagnetic calorimeters

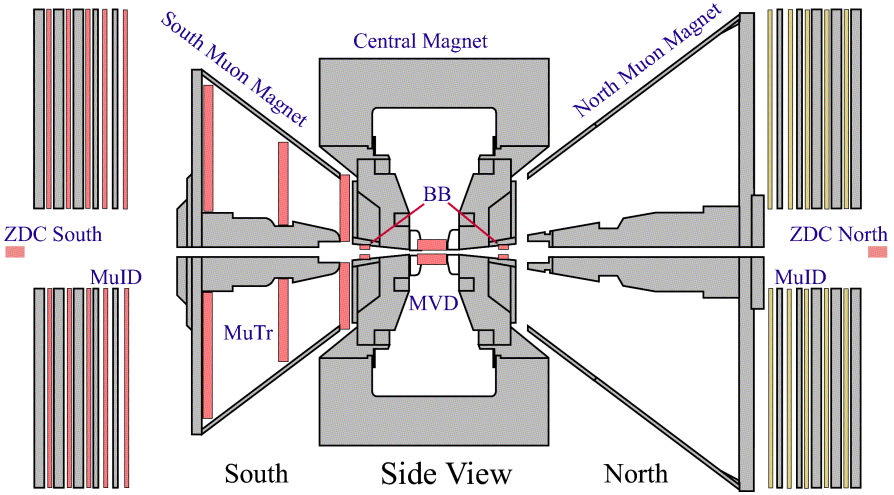
Each of two central arms covers an azimuthal angle π/2 and pseudorapidity |η|<0.35




$$\frac{\delta(p)}{p} = 0.7\% \oplus 1.1\% \, p[GeV/C] \quad \rightarrow \quad \text{DC}$$

$$\frac{\sigma(E)}{E} = \frac{5.9\%}{\sqrt{E[GeV]}} \oplus 0.8\% \quad \rightarrow \quad \text{PbGl}$$

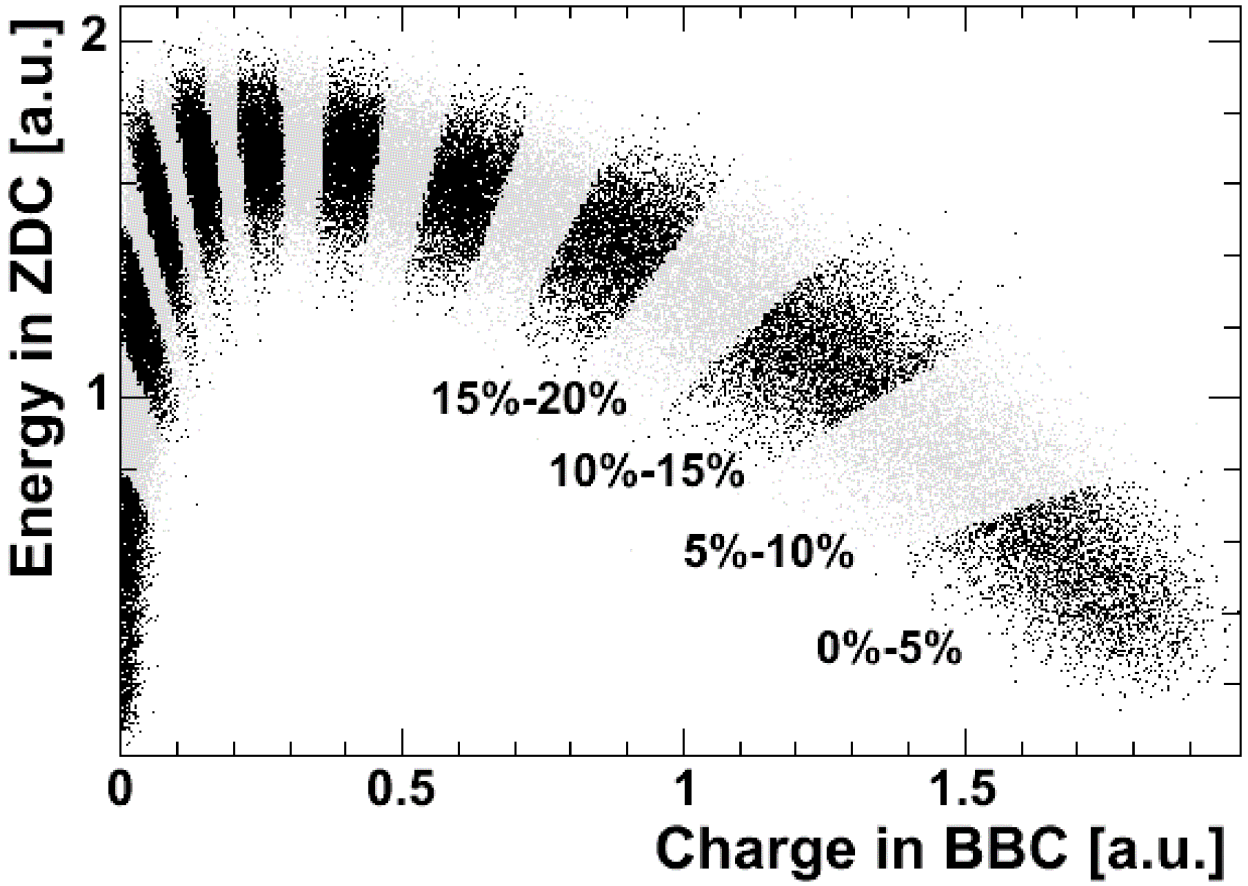
$$\frac{\sigma(E)}{E} = \frac{8.1\%}{\sqrt{E[GeV]}} \oplus 2.1\% \quad \rightarrow \quad \text{PbSc}$$




~115 ps TOF resolution

BBC and ZDC are used to determine the centrality of events, the collision vertex and also provide the minimum bias interaction trigger

# Centrality determination




Events are categorized into centrality classes by using two-dimensional cuts in the space of BBC charge versus ZDC energy

# Nuclear modification factor definition and invariant yields of charged hadrons in Au+Au at 200 GeV

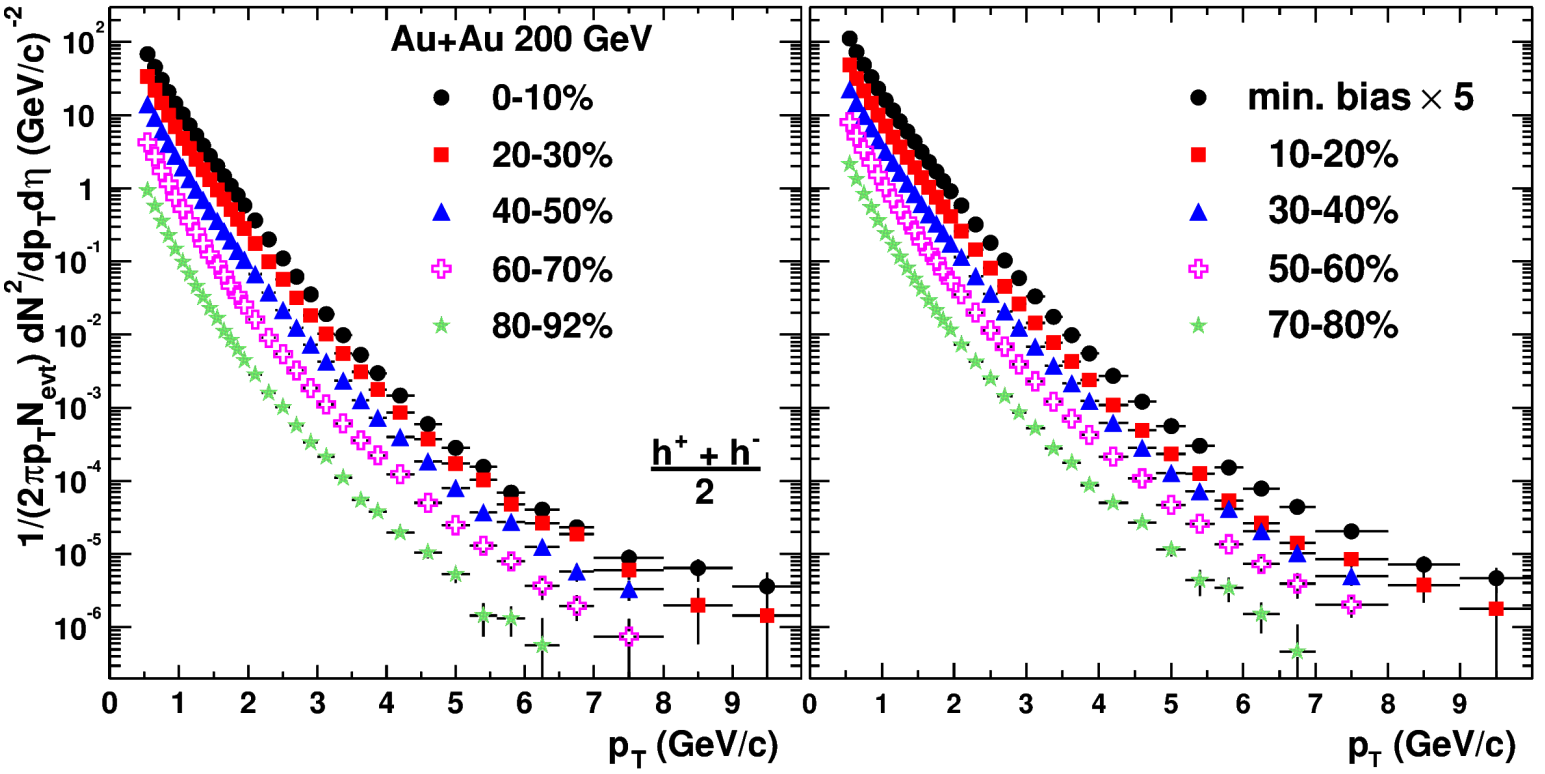
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2 N_{AA} / dy dp_T}{d^2 N_{pp} / dy dp_T}$$

here $\langle N_{coll} \rangle$ is the average number of binary collisions determined by Glauber

R_AA difference from unity is a manifestation of medium effects.

$2.7 \times 10^7$ *minimum bias events*

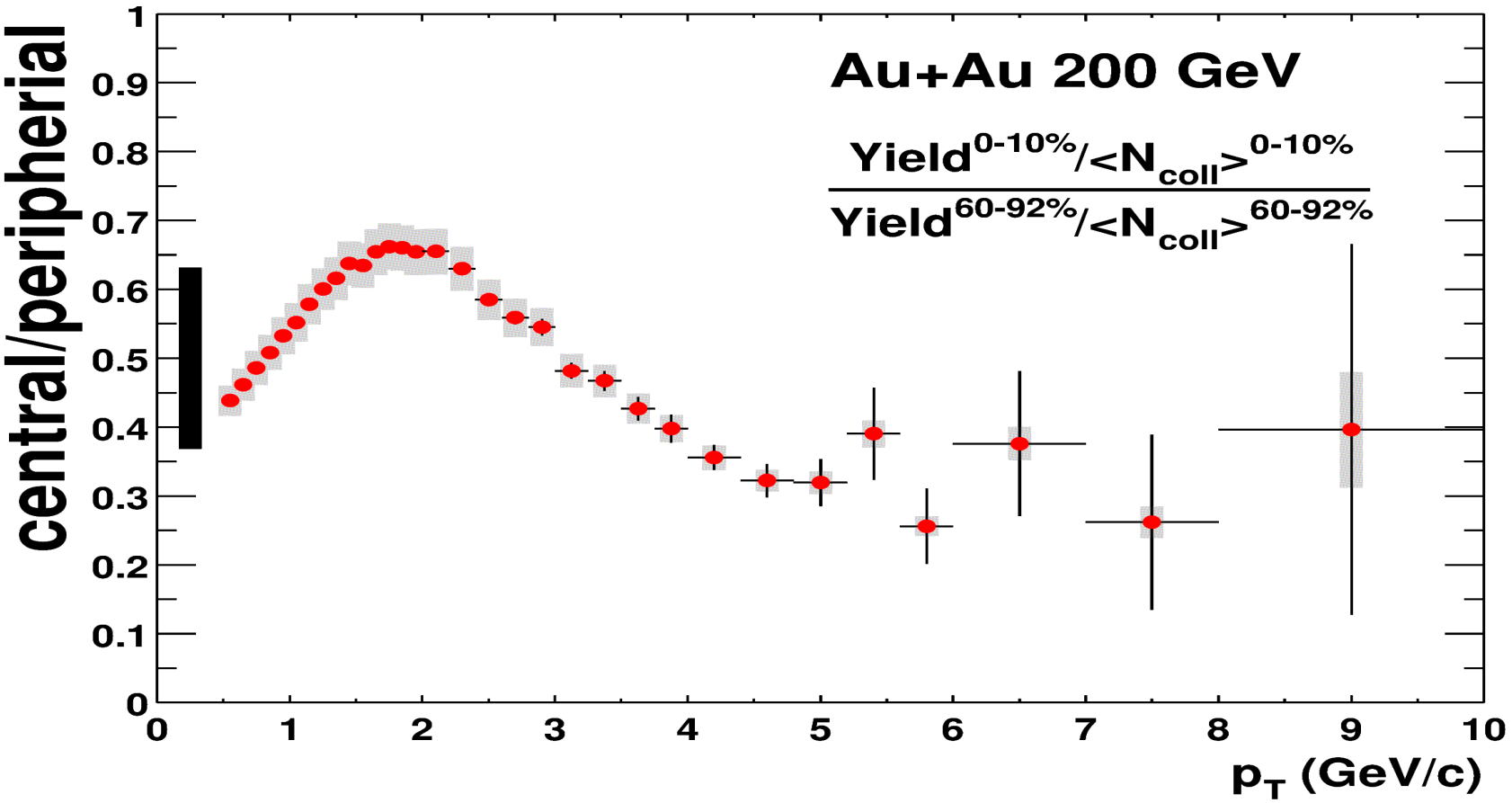
Phys. Rev. C 69, 034910 (2004)




All spectra exhibit power-law tails at high pT.

# The ratio of cenral to peripheral charge hadrons yields in Au+Au at 200 GeV

Phys. Rev. C 69, 034910 (2004)



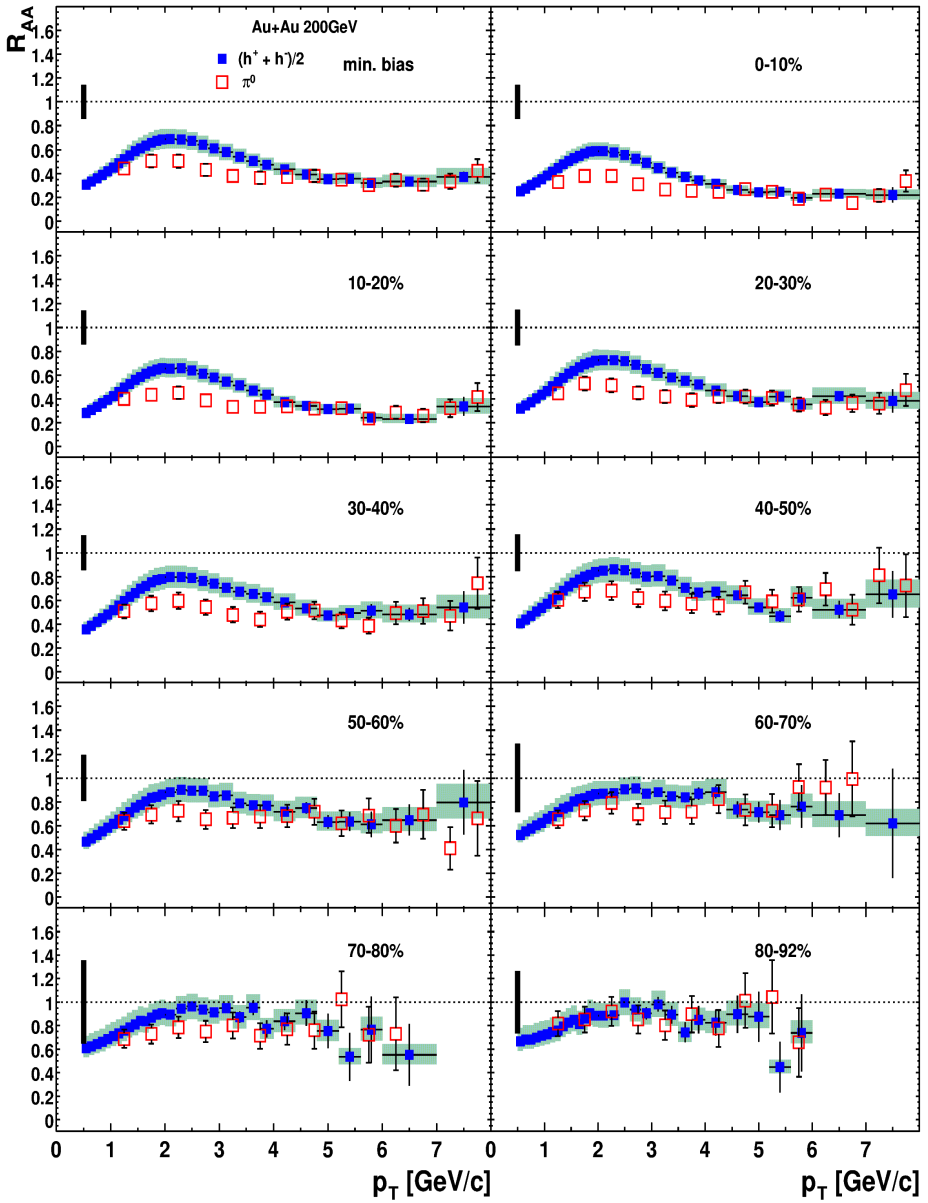

$p_T < 2\,GeV/c$ soft physics region

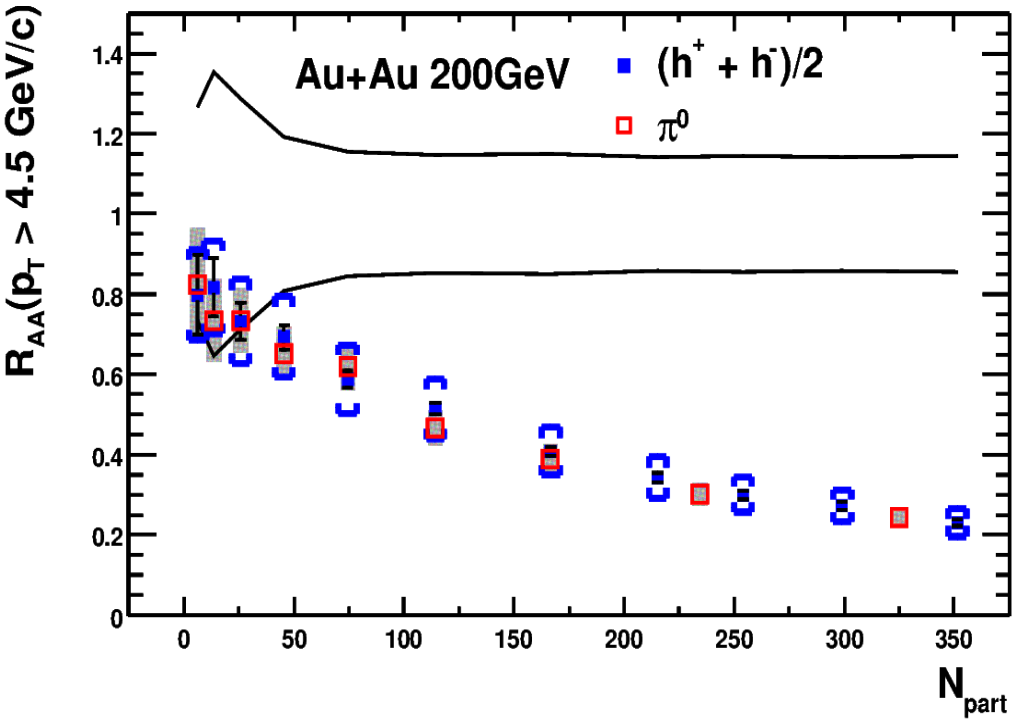
$2 < p_T < 4.5\,GeV/c$ intermediate region

$p_T > 4.5\,GeV/c$ hard scattering region

# Nuclear modification factors for charged hadrons in Au+Au at 200 GeV

Phys. Rev. C 69, 034910 (2004)

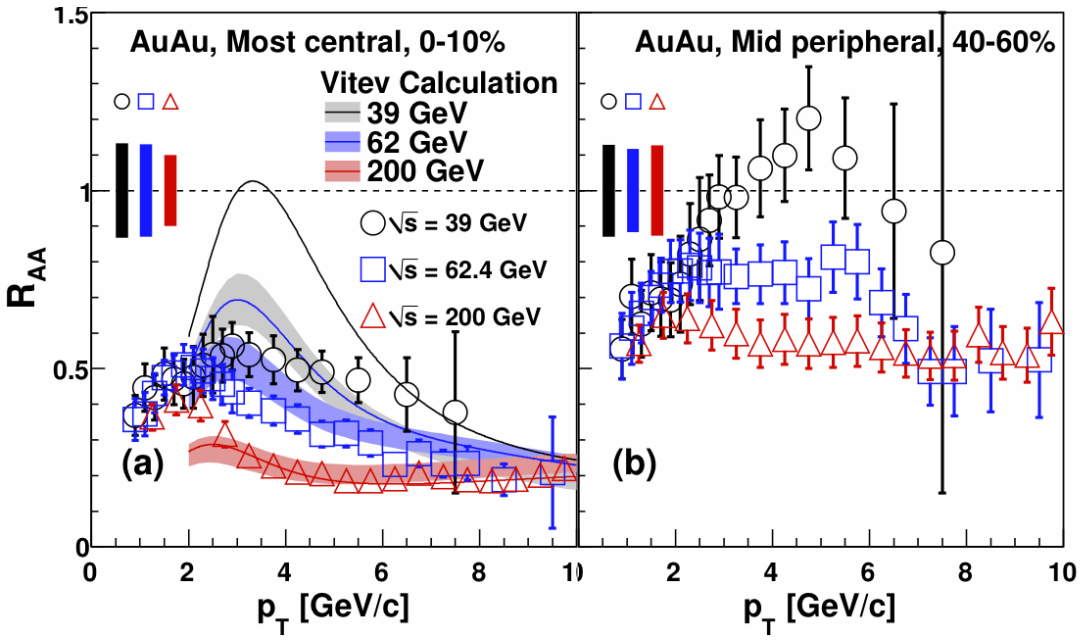



Suppression for charged hadrons and neutral pions are similar for pT > 4.5 GeV and does not depend on pT

At 1 < pT<4.5 GeV/c strong baryons enhancement could be explained by recombination models

# $\pi^0 R_{AA}$ dependence on the beam energy in AuAu collisions




$1.03\times10^{9}$ *MinB evts at* $200\,GeV$

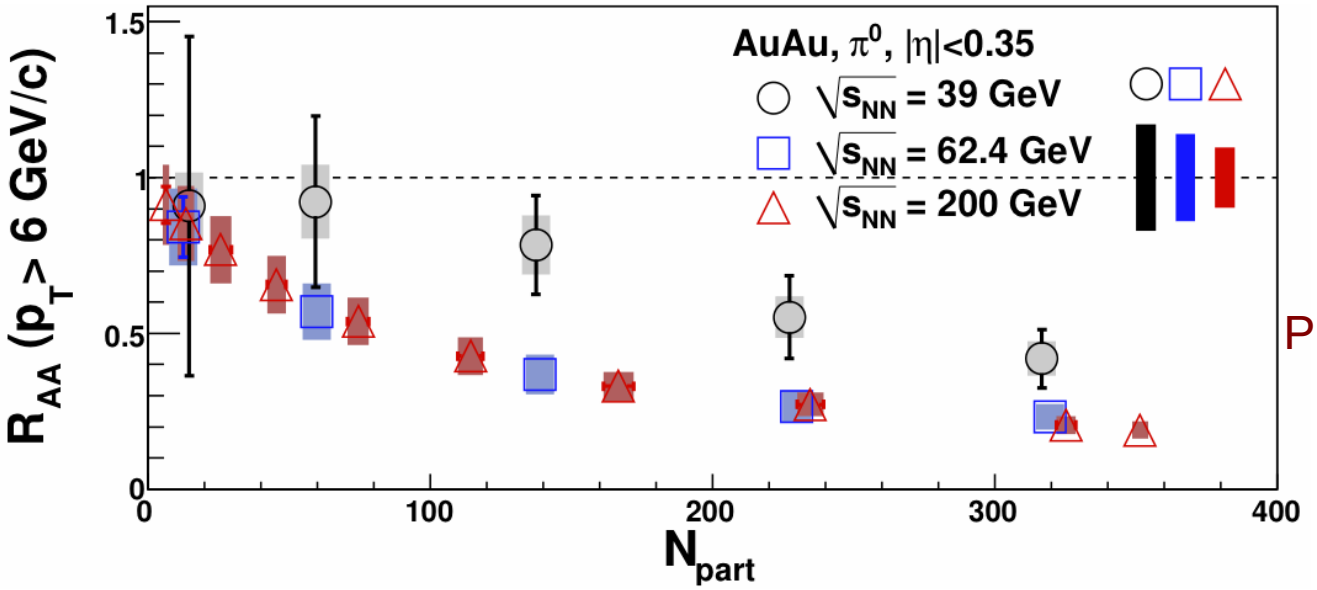
$7.0\times10^{8}$ *MinB evts at* $62.4\,GeV$

$3.5\times10^{8}$ *MinB evts at* $39\,GeV$

significant suppression for all three energies is in the most central collisions (0-10%)

R_AA is consistent with unity above pT > 3 GeV/c in midperipheral collisions (40-60%) at 39 GeV

R_AA decreases with increasing centrality even for the lowest-energy system



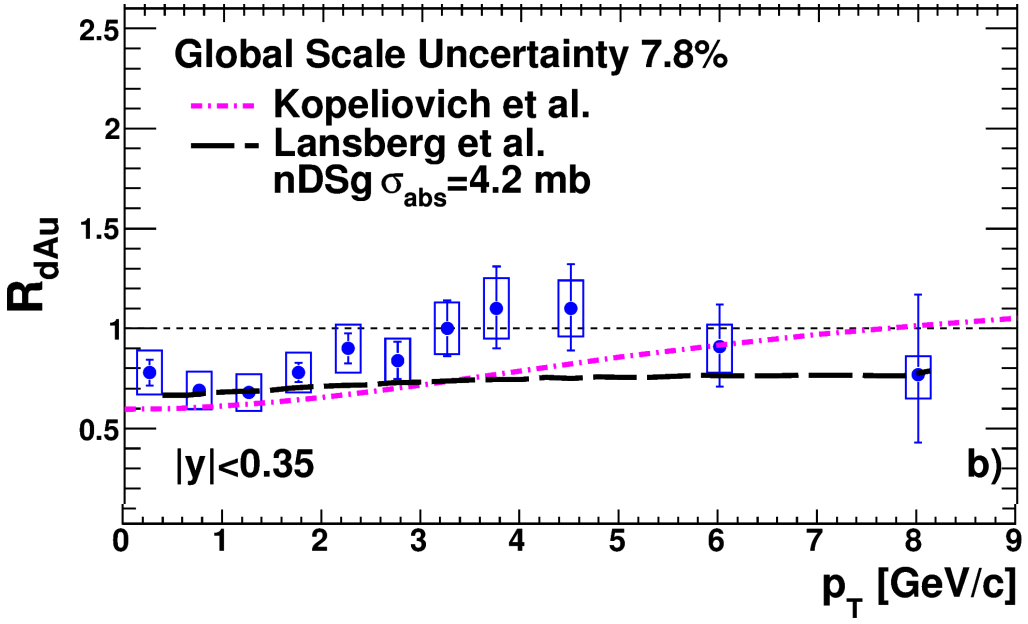

at pT > 6 GeV/c the suppression is the same at 62 and 200 GeV for all centralities

Phys. Rev. Lett. 109, 152301 (2012)

# $J/\Psi$ Nuclear modification factors in d+Au Au+Au and Cu+Cu at 200 GeV

$62.7\,nb^{-1}$ *for* $d+Au$

$J/\Psi \rightarrow e^{+}e^{-}$



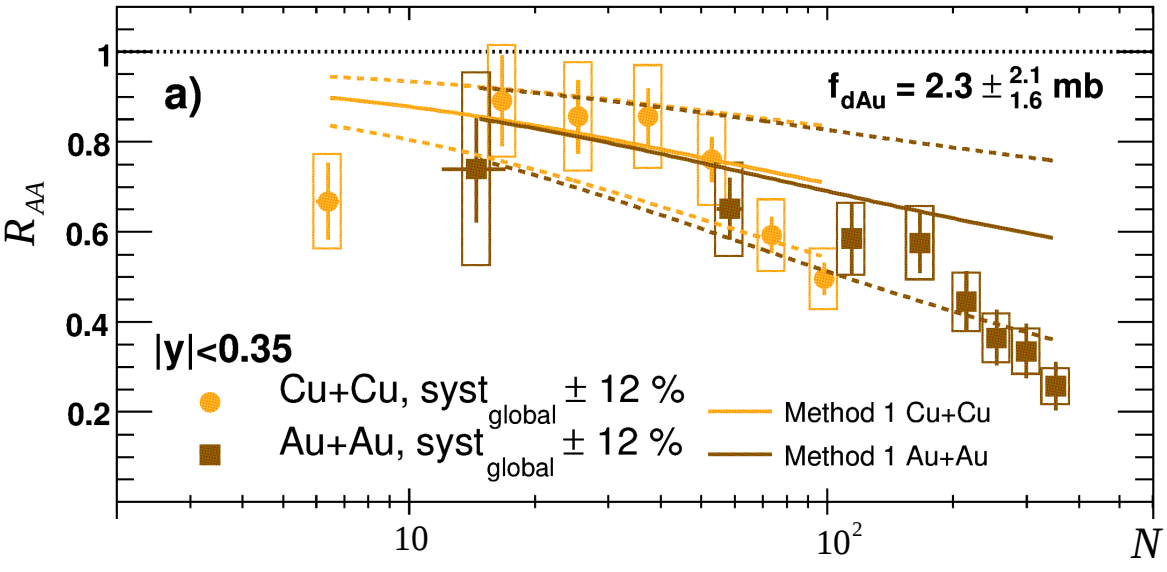

$9.9\times10^{8}$ *minimum bias Au+Au events*

$2.1\,nb^{-1}$ *for Cu+Cu*

R_dAu gradually increases to 1.0 for pT > 1 GeV/C

Phys. Rev. C 87, 034904 (2013)

Significant J/psi suppression is observed for central Au + Au and Cu+Cu collisions




Phys. Rev. Lett. 101, 122301 (2008)

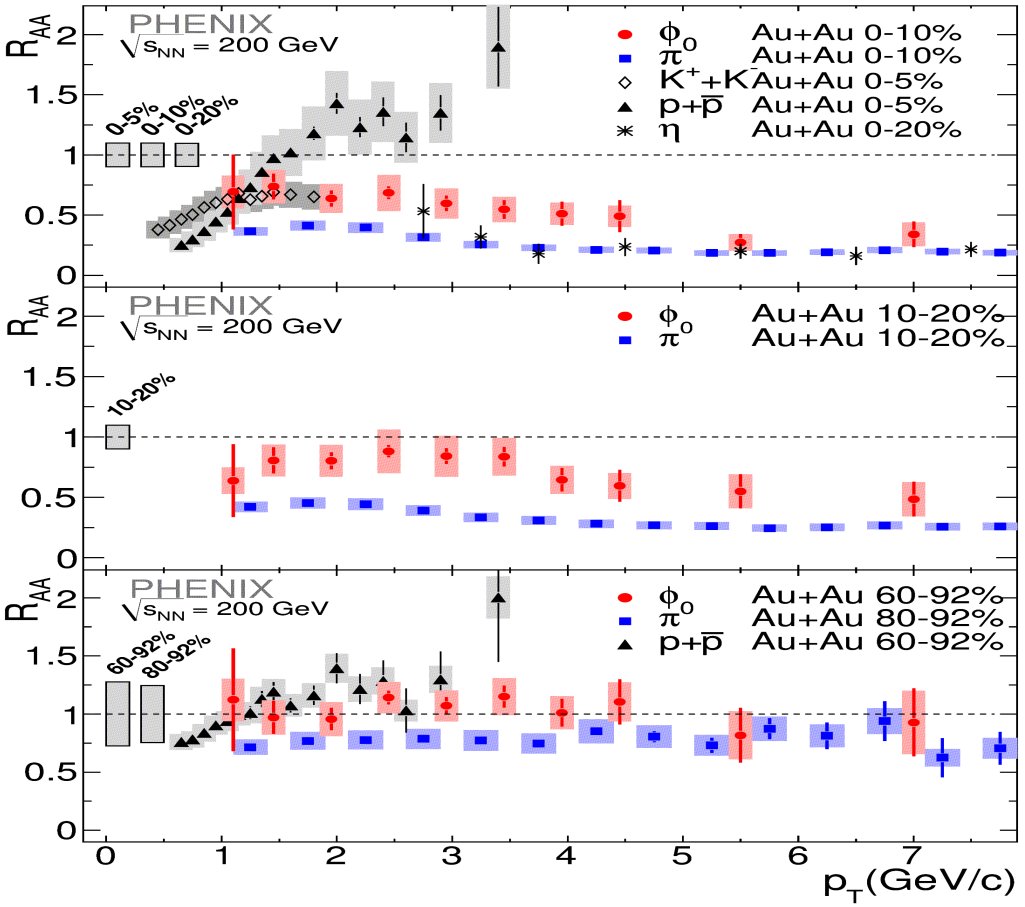
R_AA decreases with increasing Npart

At similar values of Npart R_AA values agree within errors for Cu+Cu and Au+Au collisions

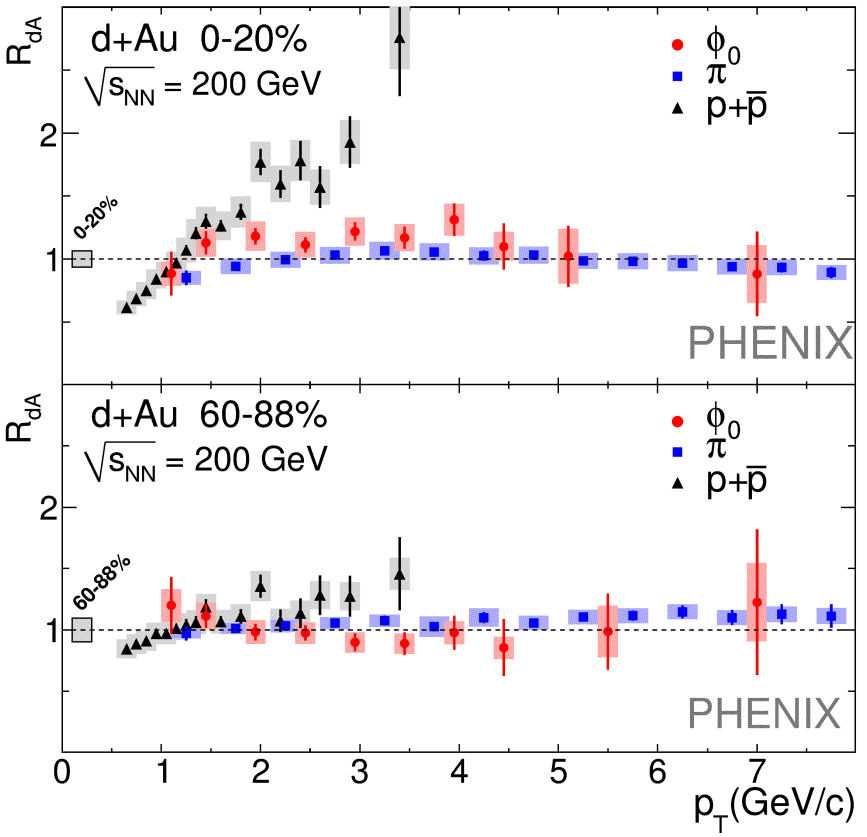
# $\phi$ nuclear modification factors in Au+Au and d+Au collisions at 200 GeV

Phys. Rev. C83 , 024909 (2011) $0.82\times10^{9}$ *MinB Au+Au evts*

$\phi \rightarrow K^{+}K^{-}$




$1.69\times10^{9}$ *MinB d+Au evts*



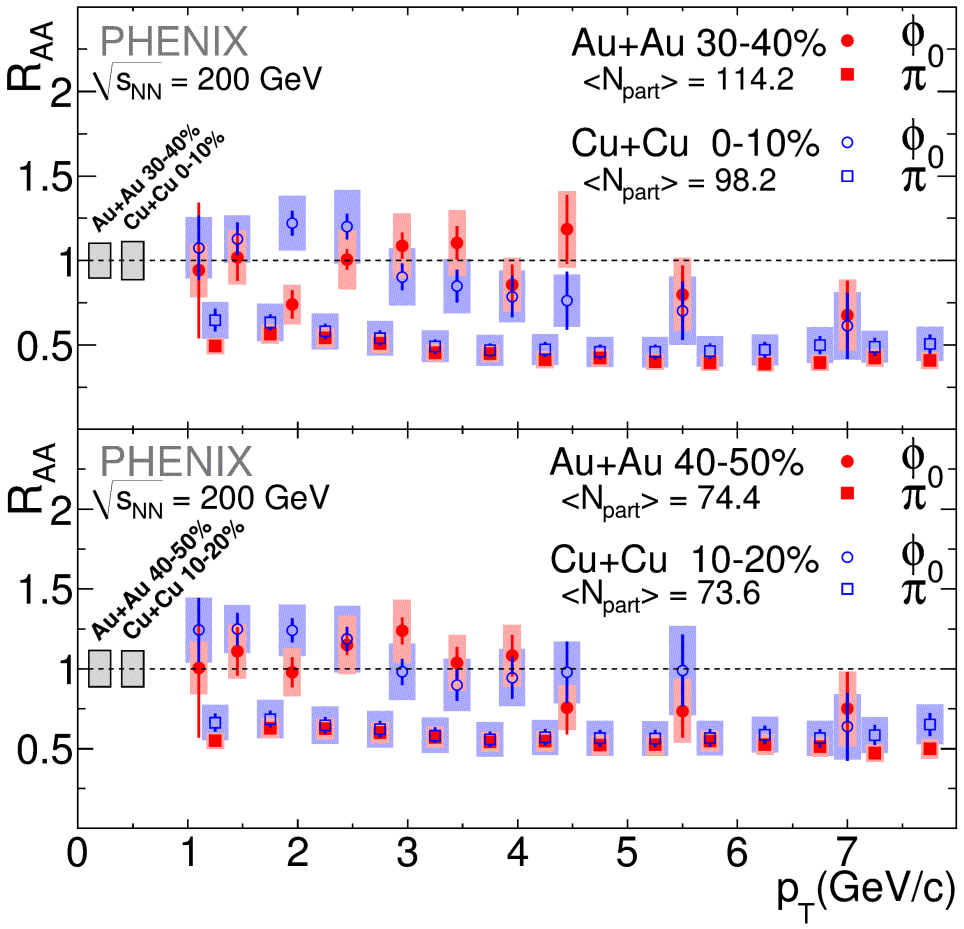

For all centralities the phi R_AA shows less suppression than pi0 and eta at 2 < pT < 5 GeV/c

At pT > 5 GeV/c the phi R_AA becomes comparable to the pi0 and eta R_AA in central Au+Au collisions

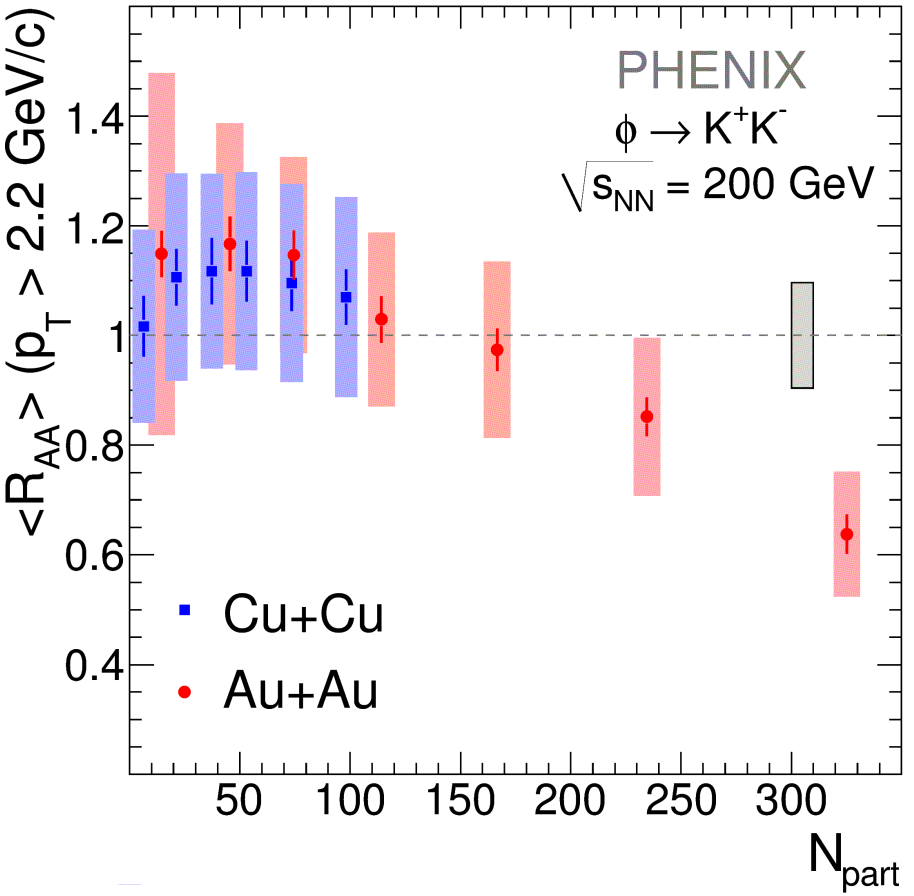
R_dA for phi and pi0 are similar. So cold nuclear effects are not responsible for the differences between phi and pi0 in Au + Au and Cu + Cu collisions

# $R_{AA}$ for $\phi$ in Au+Au and Cu+Cu collisions at 200 GeV

Phys. Rev. C83 , 024909 (2011)



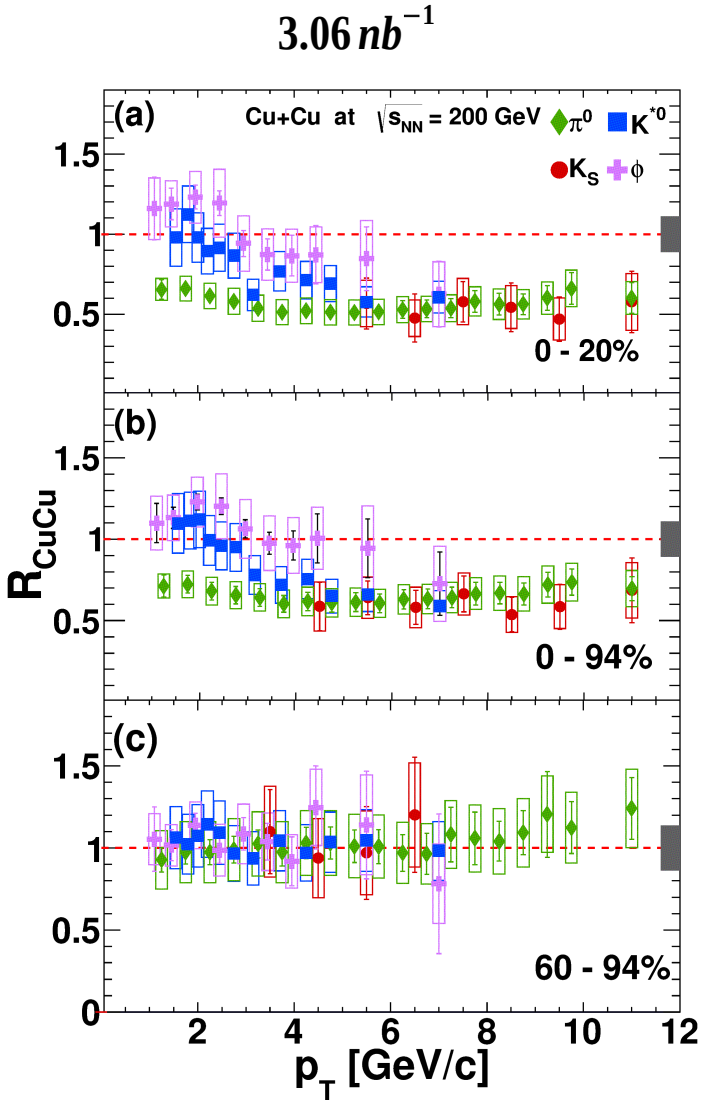

$0.78\times10^{9}$ *MinB Cu+Cu evts*




level of the phi and pi0 suppression in Au+Au and Cu+Cu is similar for the same number of participants

# $R_{CuCu}$ for $K^0_s$ and $K^{*0}$ in Cu+Cu collisions at 200 GeV

ArXiv:1405.3628; will be published in PRC $K^0_s \to \pi^0\pi^0$ $K^{*0} \to K^+\pi^-$



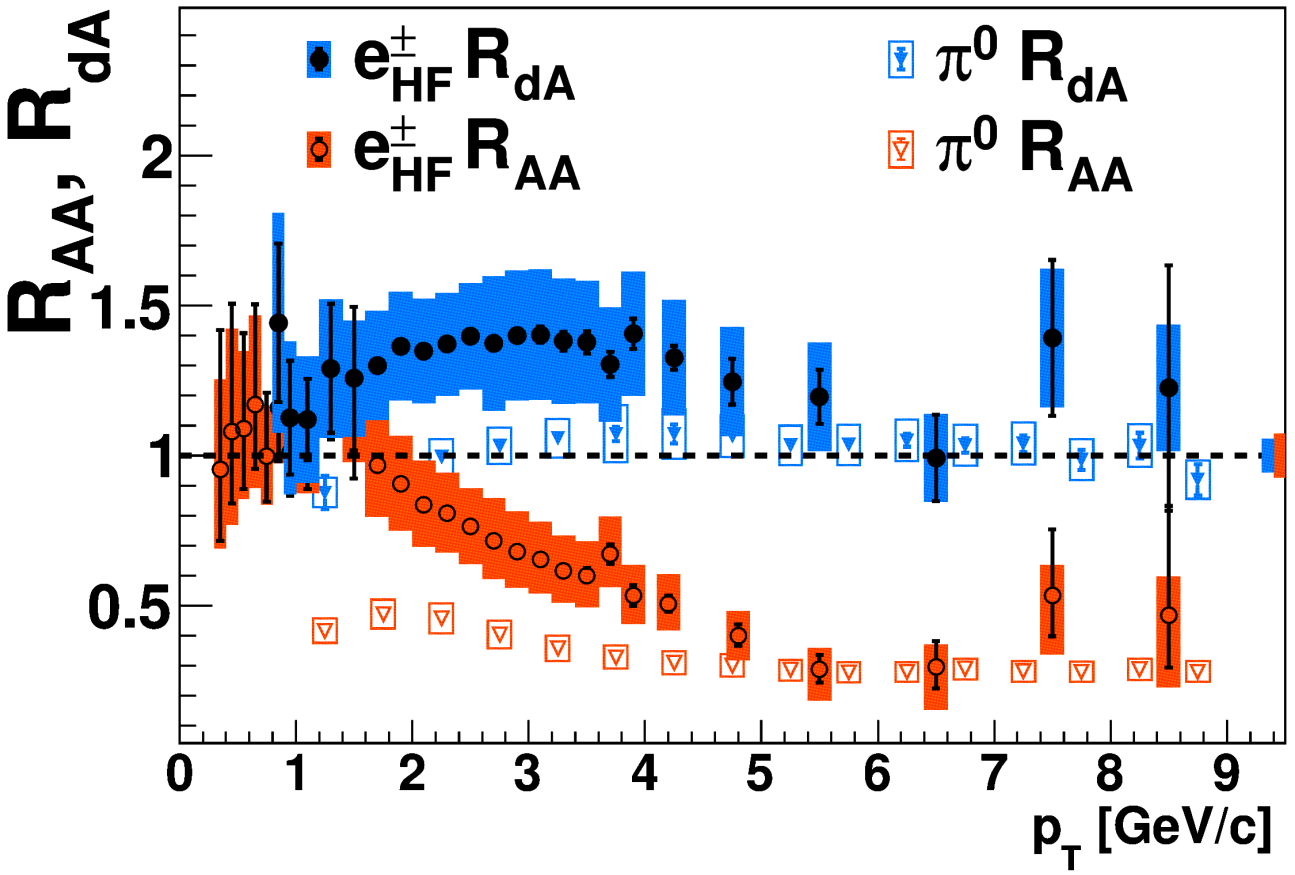

In central and MB collisions the significant suppression is the same within the uncertainties for K0, K-star0, phi and pi0 at pT > 5 GeV/c, indicating that its mechanism does not depend on the particle species.

In central and MB collisions phi and K-star0 shows less suppression than pi0 at 2 < pT < 5 GeV/c. Cronin effect, strong radial flow, recombination effects have been invoked to explain R_AA behaviour in this intermediate pT region. Which physics mechanism prevails in this pT region is open question.

Mass dependence of the suppression mechanism in the intermediate pT region in central and MB collisions provides additional constraints to the models attempting to quantitatively reproduce nuclear modification factors.

In peripheral collisions there are no any suppressions for K0, K-star0, phi and pi0 at all pT.

# The nuclear modification factors for Minimum Bias d+Au and Au+Au collisions at 200 GeV for pi0 and electrons from the decays of hadrons containing open heavy flavor




$7.48 \times 10^8$ *MinB Au+Au evts*

$80\ nb^{-1}$ *for d+Au*

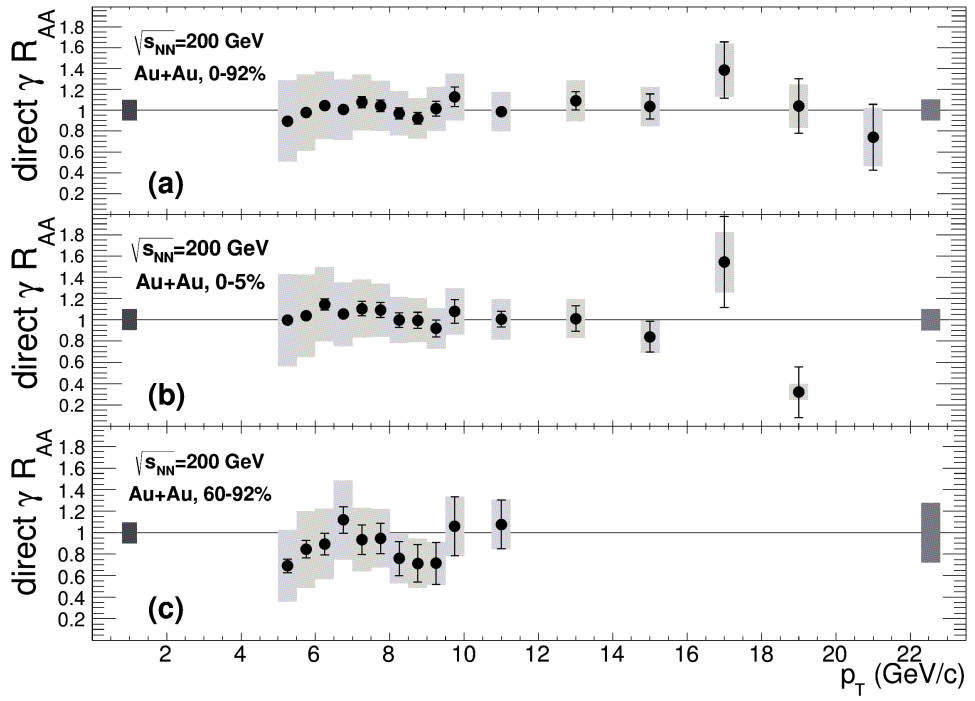
Phys. Rev. Lett. 109, 242301 (2012)

R_AA values of HF electrons in central Au+Au collisions show less suppression than pi0 at 1.5 <pT< 5 GeV/c

In central d+Au collisions, the nuclear modification factor RdA at 1.5 < pT < 5 GeV/c displays a significant enhancement of Heavy Flavor electrons.This implies that the suppression of HF electrons in central Au+Au collisions at 200 GeV is not an initial state CNM effect, but rather is due to the hot nuclear medium.

Above pT > 5 GeV/c, where the CNM effects on HF electrons and pi0 are small, their RAA values are consistent within uncertainties

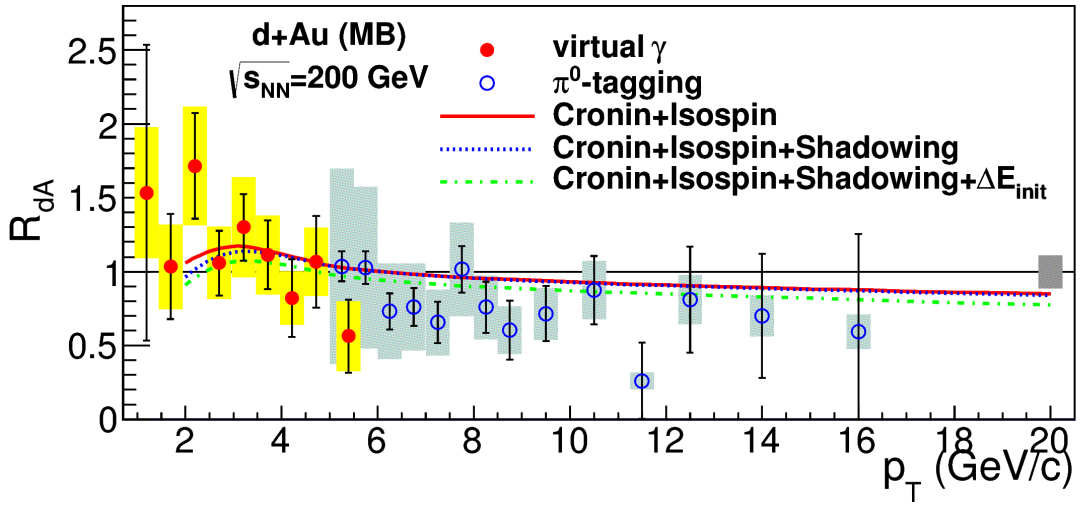
# Nuclear modification factors for direct photons in Au+Au and d+Au at 200 GeV




Phys. Rev. Lett. 109, 152302 (2012)

$1.03\times10^9$ *minimum bias events for Au+Au*

No suppression for all centralities in Au+Au and d+Au collisions




Phys. Rev. C 87, 054907 (2013)

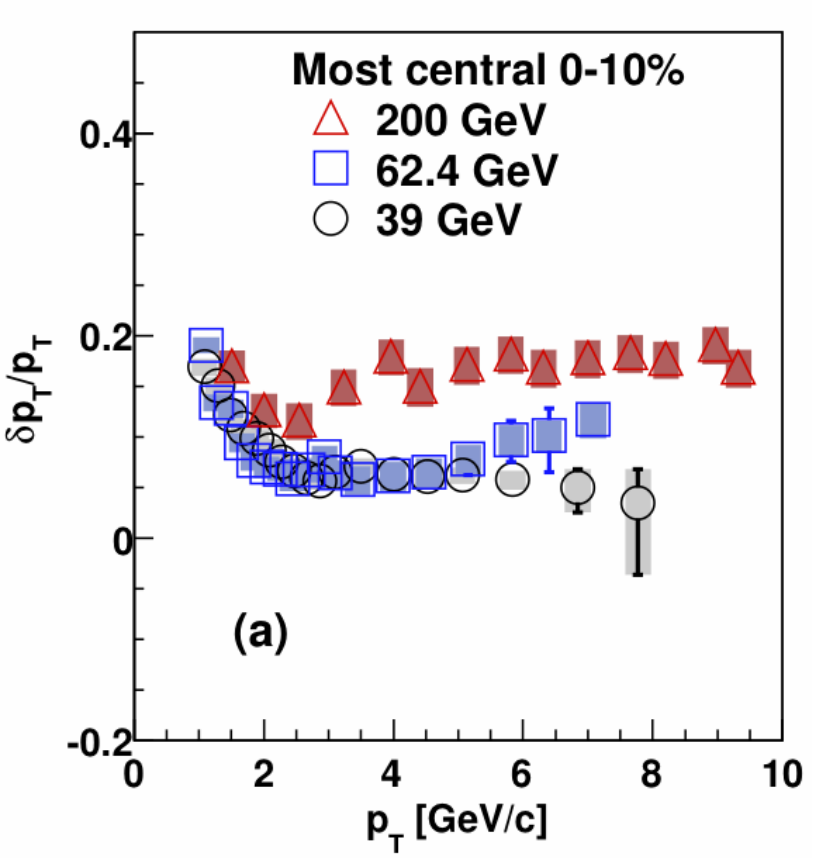
# Conclusions

- The hadrons yields per nucleon-nucleon collision in central collisions of heavy ions are significantly suppressed compared to peripheral and nucleon-nucleon collisions.
- The charged hadron suppression is similar to the suppression of pi0, phi, eta and Heavy Flavor electrons in central Au+Au collisions at 200 GeV for pT > 5 GeV/c.
- The data clearly indicate that there is no suppression of high pT hadrons in d+Au collisions.
- Significant pi0 suppression for Au+Au collisions is observed in the most central collisions (0-10%) for all three energies 39, 62.4 and 200 GeV. R_AA decreases with increasing centrality even for the lowest-energy system at 39 GeV. At pT > 6 GeV/c the suppression is the same at 62.4 and 200 GeV for all centralities.
- The level of the phi suppression in Au+Au and Cu+Cu collisions at 200 GeV is similar for the same number of participants. The same is valid for j/psi suppression in Au+Au and Cu+Cu.
- No any suppressions for all centralities in Au+Au and d+Au collisions at 200 GeV for direct photons.

# Backup

# The average parton momentum loss in Au+Au collisions at 39, 62.4 and 200 GeV/c

Phys. Rev. Lett. 109, 152301 (2012)




$1.03\times10^{9}$ *MinB evts at* $200\,GeV$

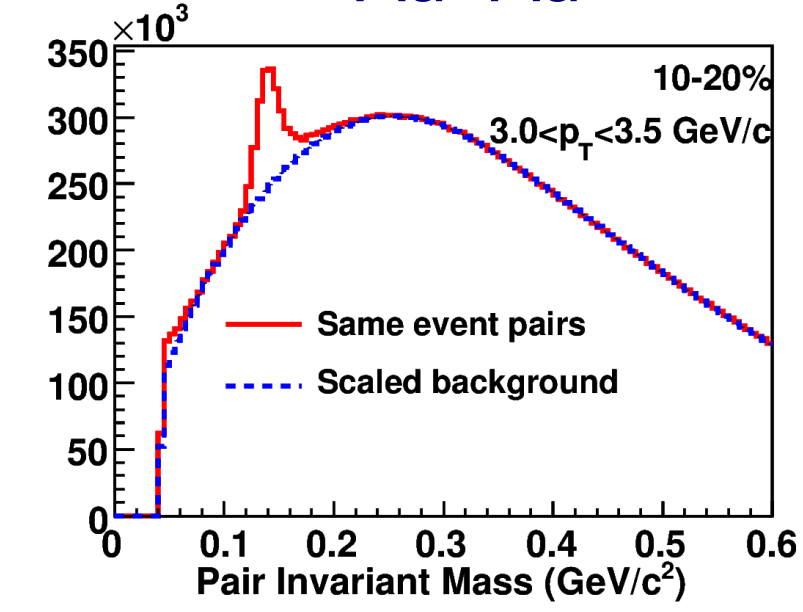
$7.0\times10^{8}$ *MinB evts at* $62.4\,GeV$

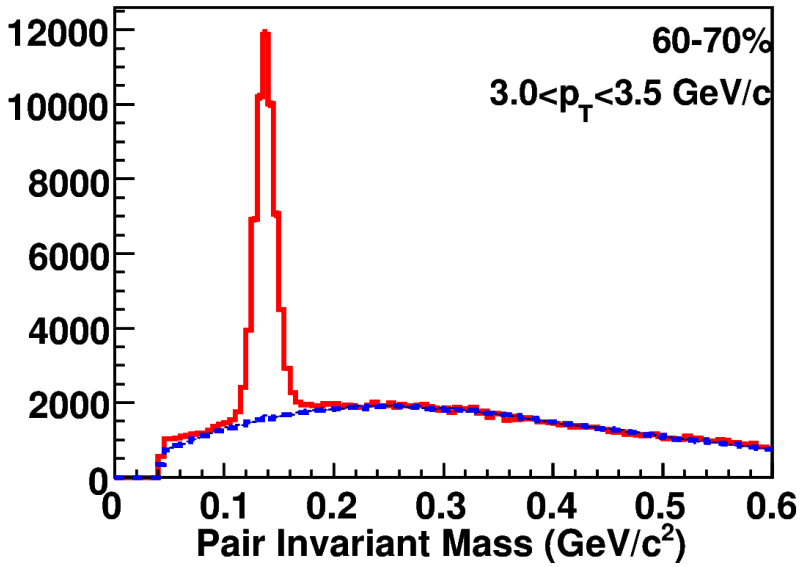
$3.5\times10^{8}$ *MinB evts at* $39\,GeV$

partons in 200 GeV collisions suffer the largest average momentum loss compared to the lower energies.

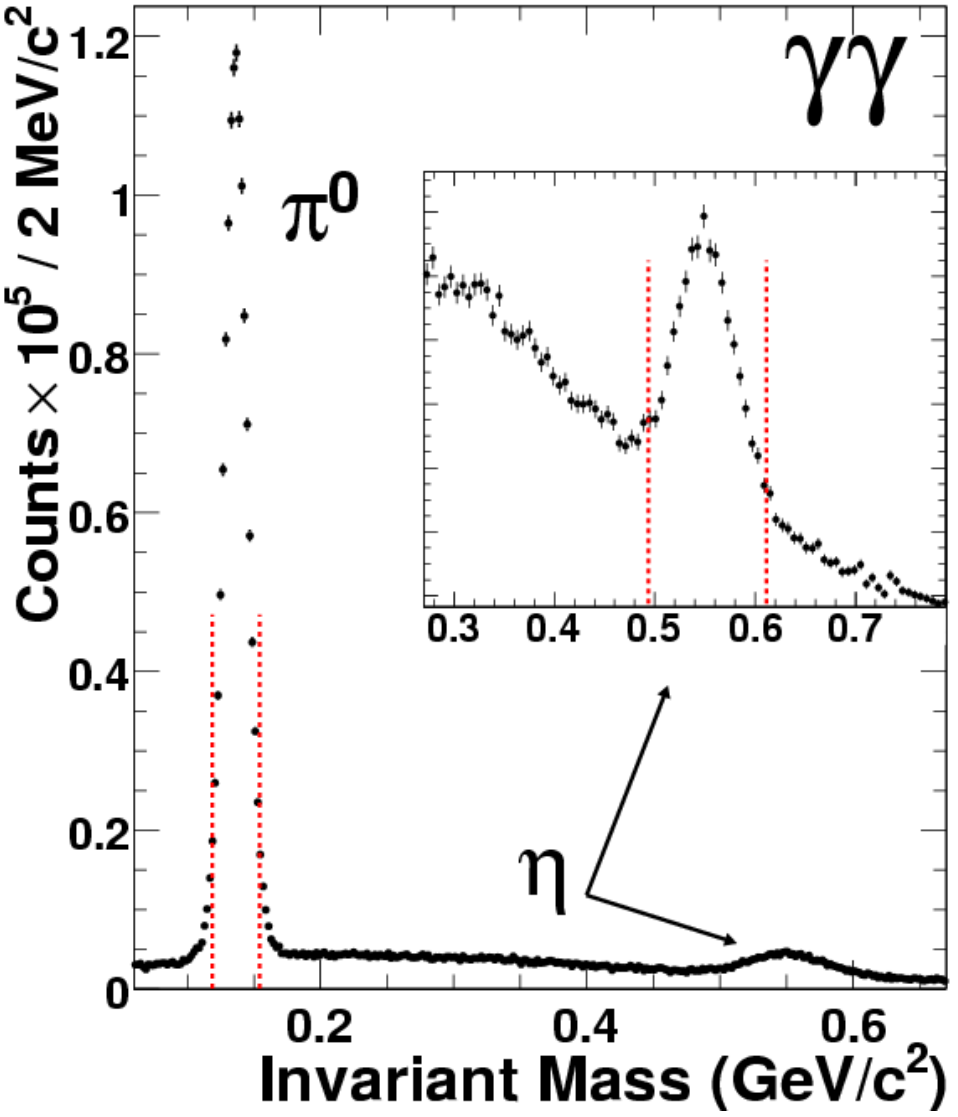
# Photon pair invariant mass distributions in AuAu and pp collisions at 200 Gev

## Au+Au




## p+p



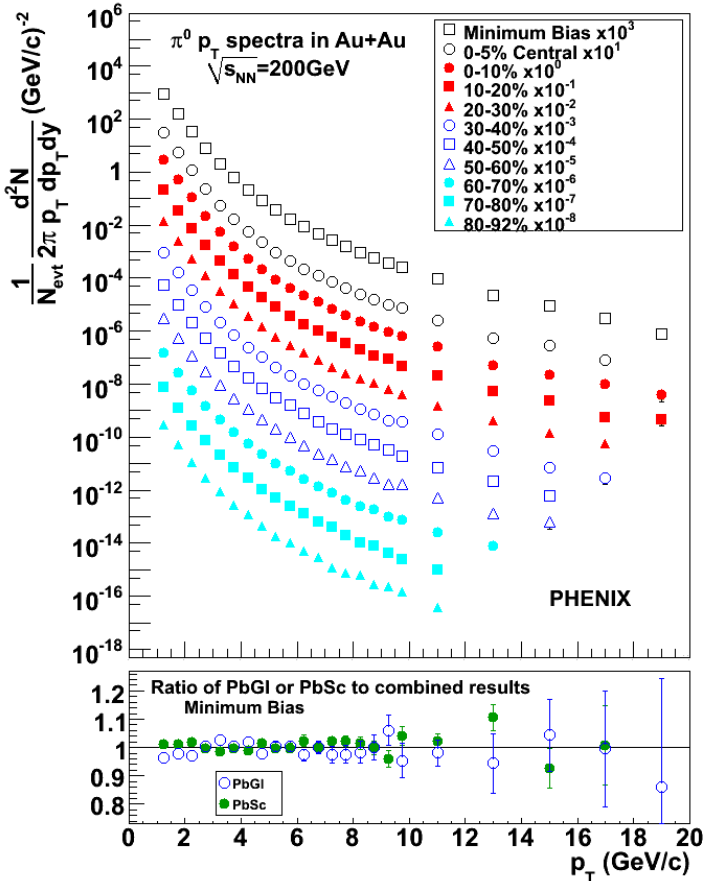
# Nuclear modification factor definition and invariant $\pi^0$ yields in Au+Au and p+p at 200 GeV

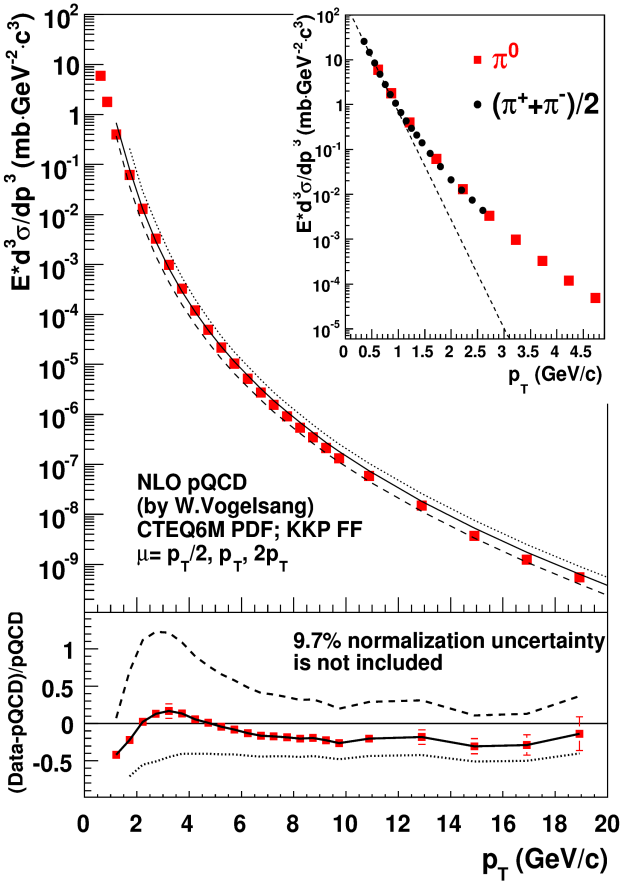
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2 N_{pp}/dydp_T}$$

here $\langle N_{coll} \rangle$ is the average number of binary collisions determined by Glauber

$1.03 \times 10^9$ minimum bias AuAu events $2.5\, pb^{-1}$ luminosity in pp

Phys. Rev. Lett. 101, 232301 (2008)




Fit to $(A/p_T)^n$ *for* $p_T > 5\,GeV/C$

$n = 8.00 \pm 0.12$ *for* $Au+Au(0-5\%)$

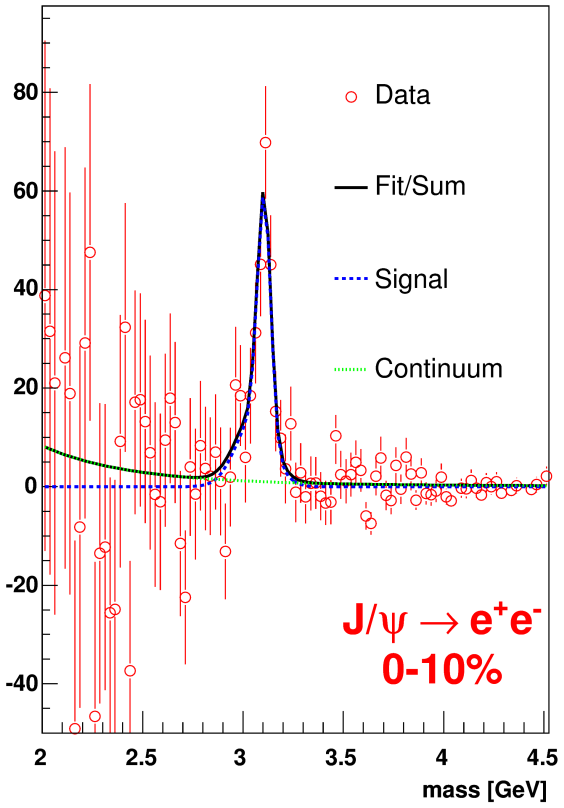
$n = 8.06 \pm 0.08$ *for* $Au+Au(80-92\%)$

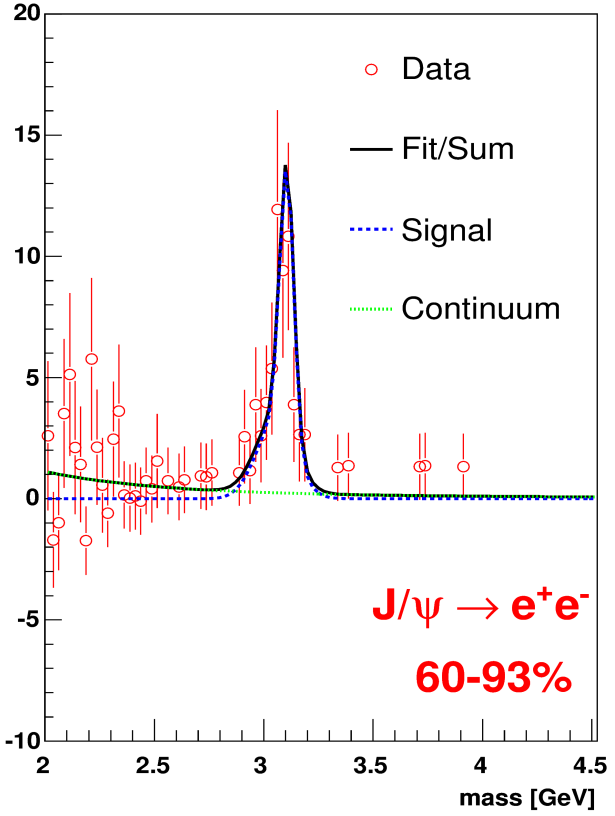
Phys. Rev. D 76, 051106 (2007)

$n = 8.22 \pm 0.09$ *for* $p+p$

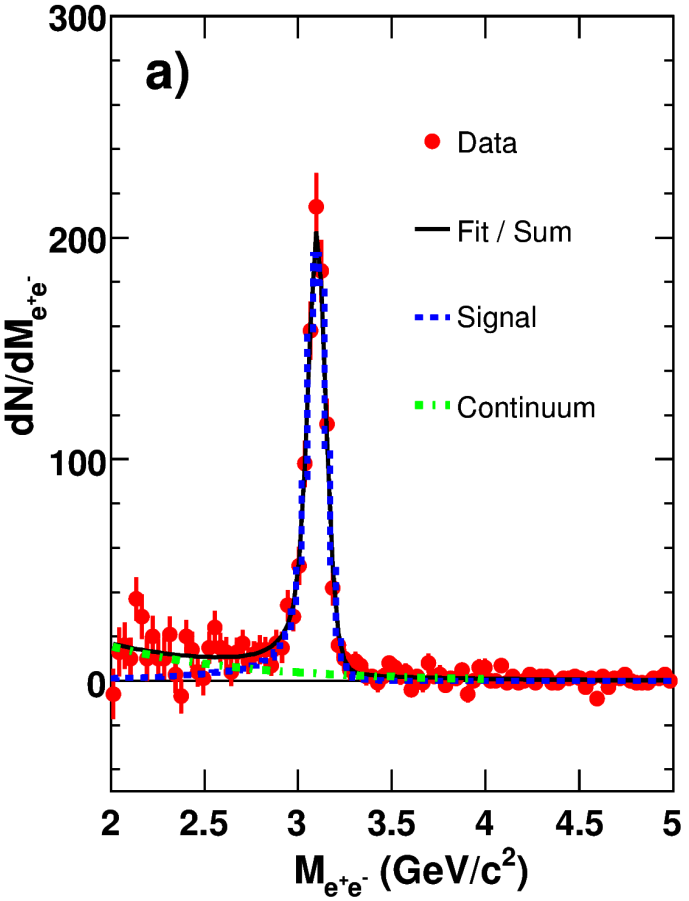
# $e^+ e^-$ invariant mass distributions in AuAu and pp collisions at 200 GeV

Au+Au 200 GeV




p+p 200 GeV



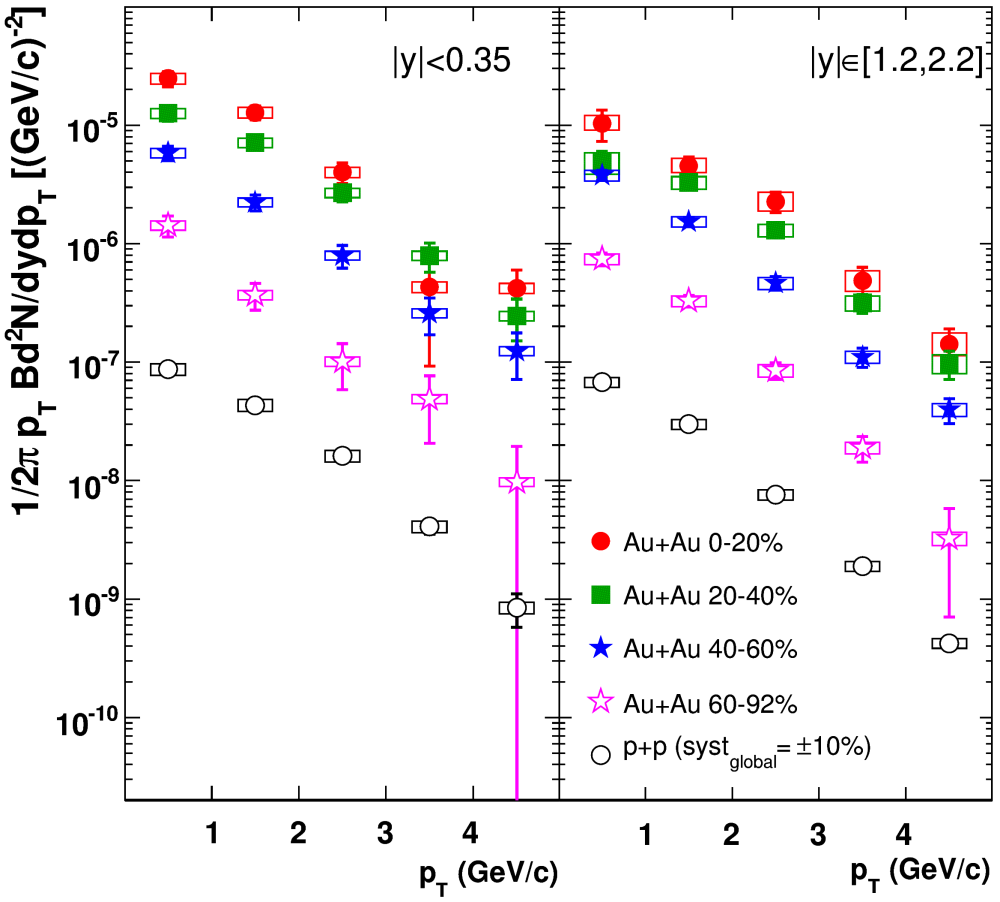
# $J/\Psi$ invariant yield for different centrality bins in Au+ Au, p+p and d+Au collisions at 200 GeV

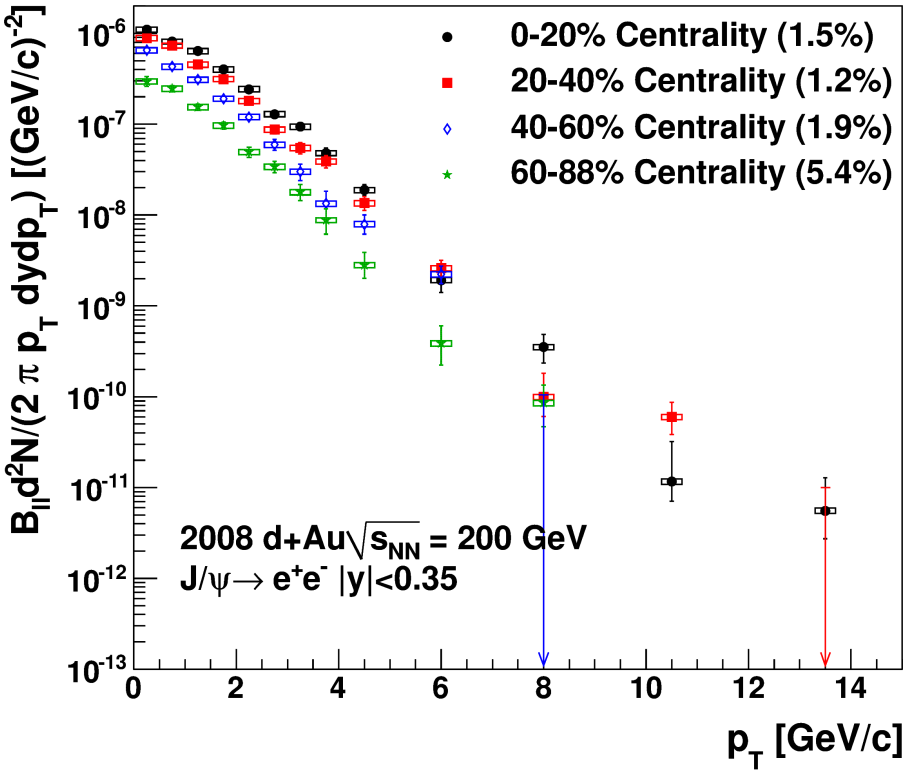
$9.9\times10^{8}$ *minimum bias events*

$62.7\,nb^{-1}$

Phys. Rev. Lett. 98, 232301 (2007)

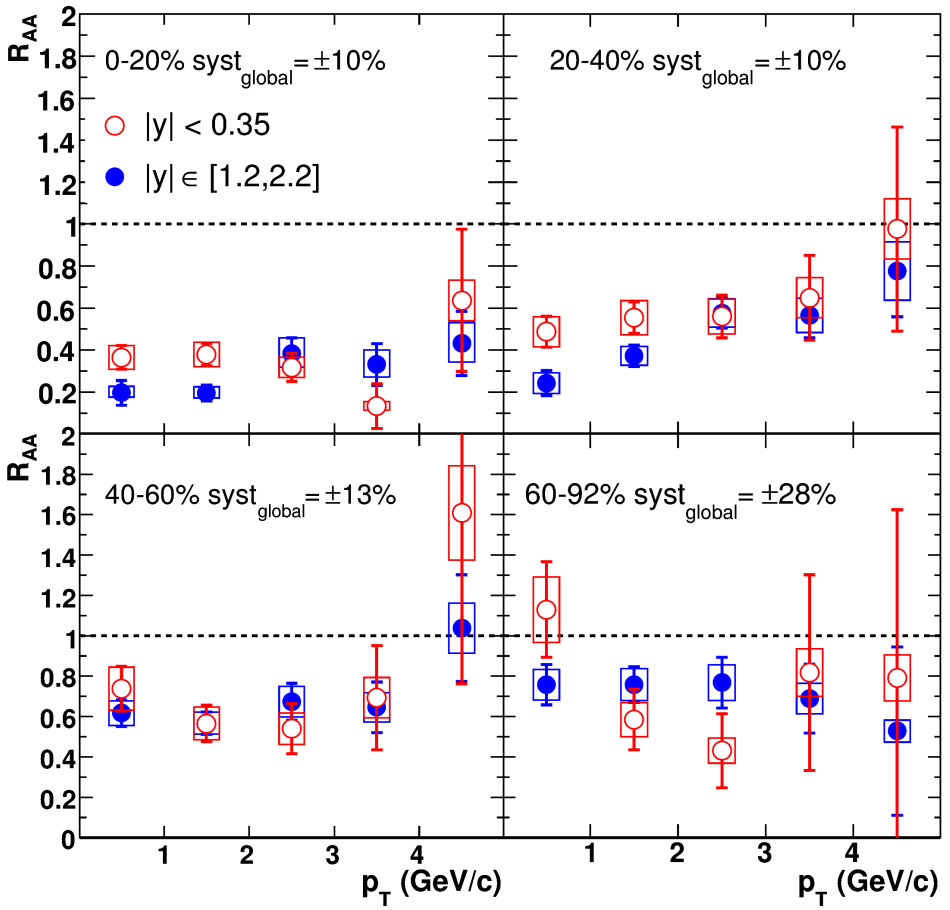
Phys. Rev. C 87, 034904 (2013)

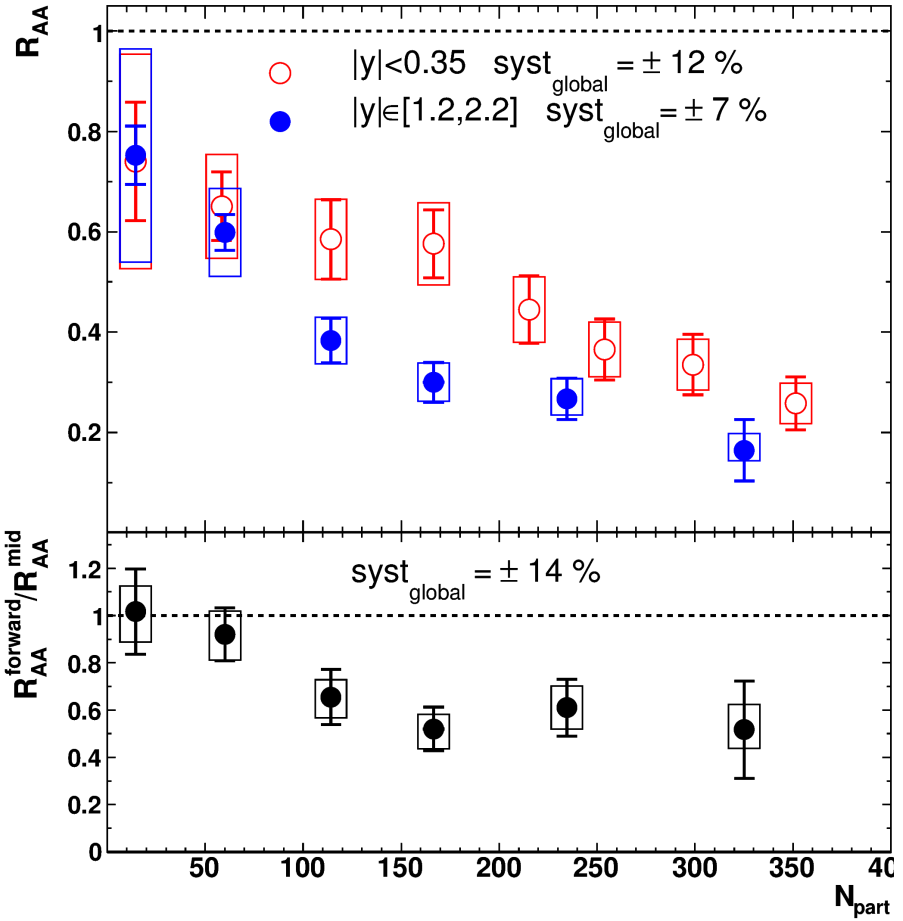


# $J/\Psi$ Nuclear modification factors in Au+Au at 200 GeV

Phys. Rev. Lett. 98, 232301 (2007)



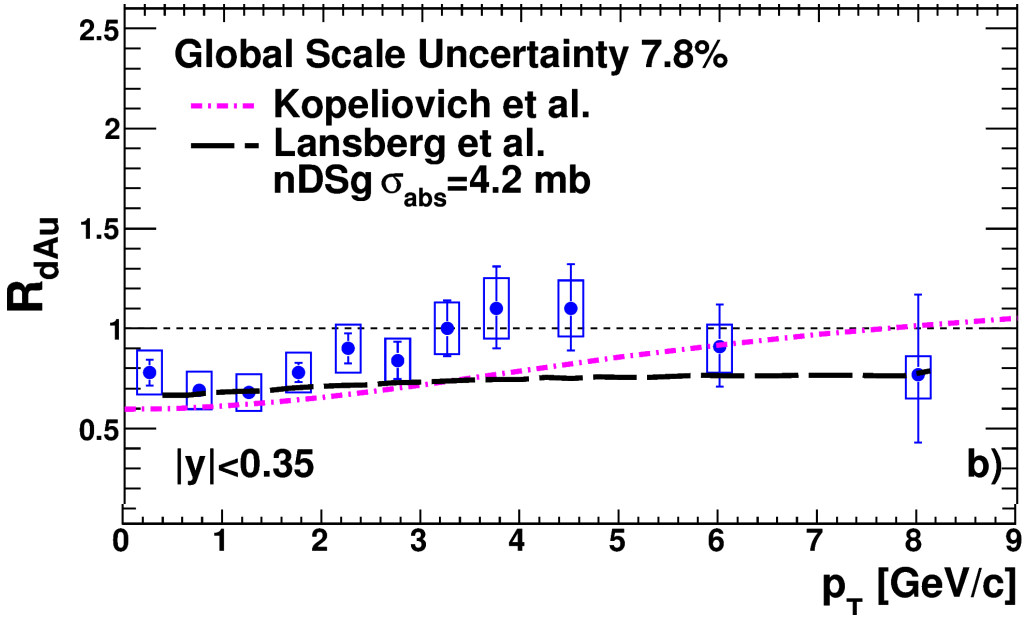




Significant J/psi suppression is observed for central Au + Au collisions

R_AA decreases with increasing Npart

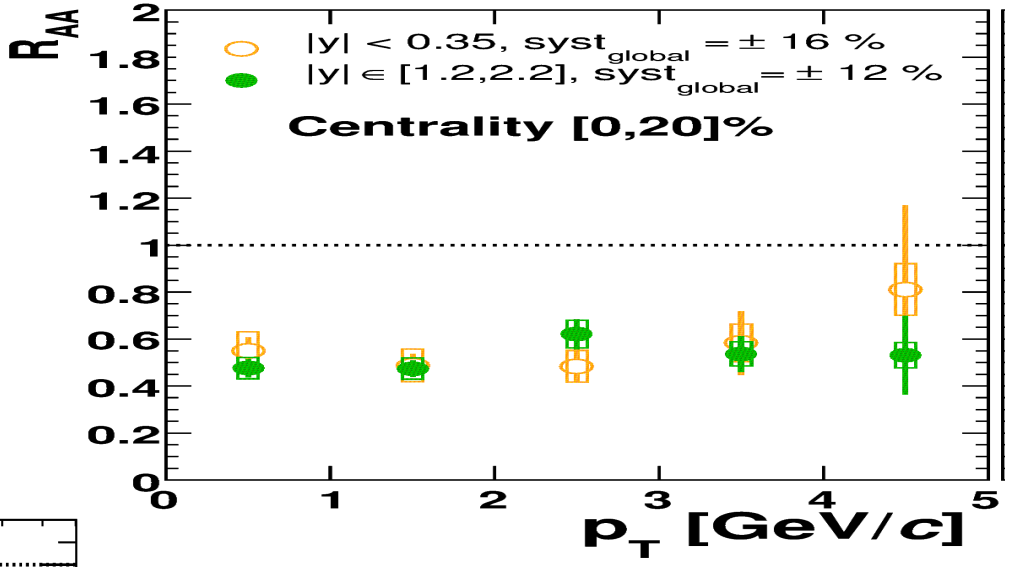
For the most central collisions, R_AA is below 0.3 at mid-rapidity

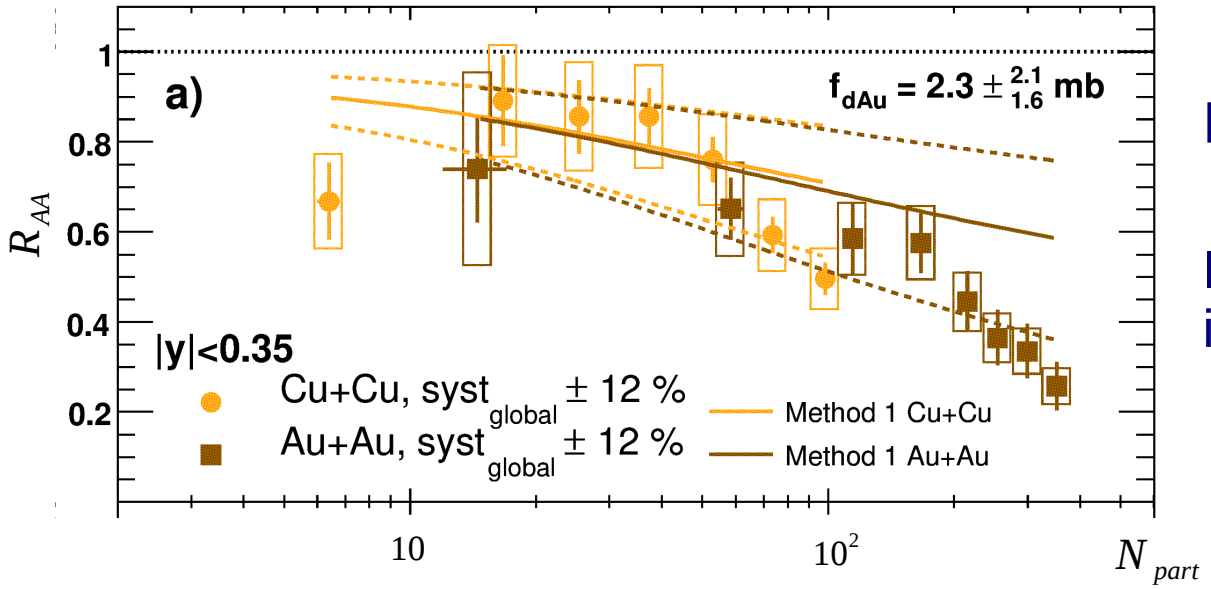
# $J/\Psi$ Nuclear modification factors in d+Au and Cu+Cu at 200 GeV




Cu+Cu

Phys. Rev. Lett. 101, 122301 (2008)




R_dAu gradually increases to 1.0 for pT > 1 GeV/C

It appears to be no pT dependence in central Cu+Cu collisions

At similar values of Npart R_AA values agree within errors for Cu+Cu and Au+Au collisions

# $\phi$ invariant yield and mass distributions in Au+Au, Cu+Cu, d+Au, p+p at 200 GeV

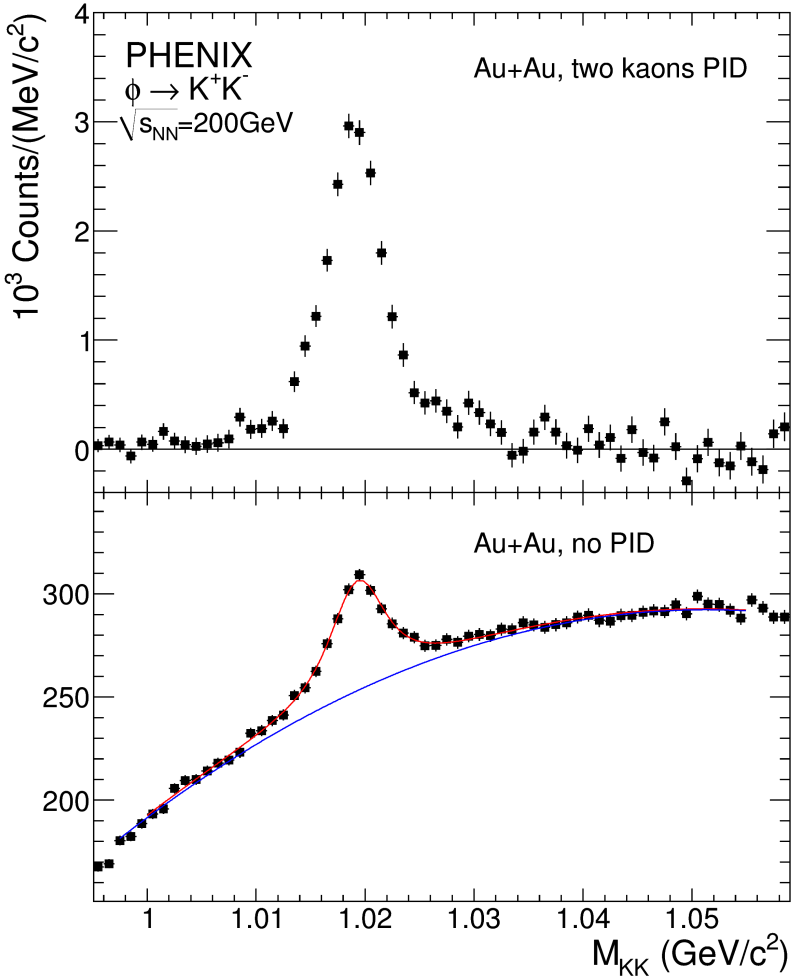
$0.82\times10^9$ *minimum bias Au+Au evts*

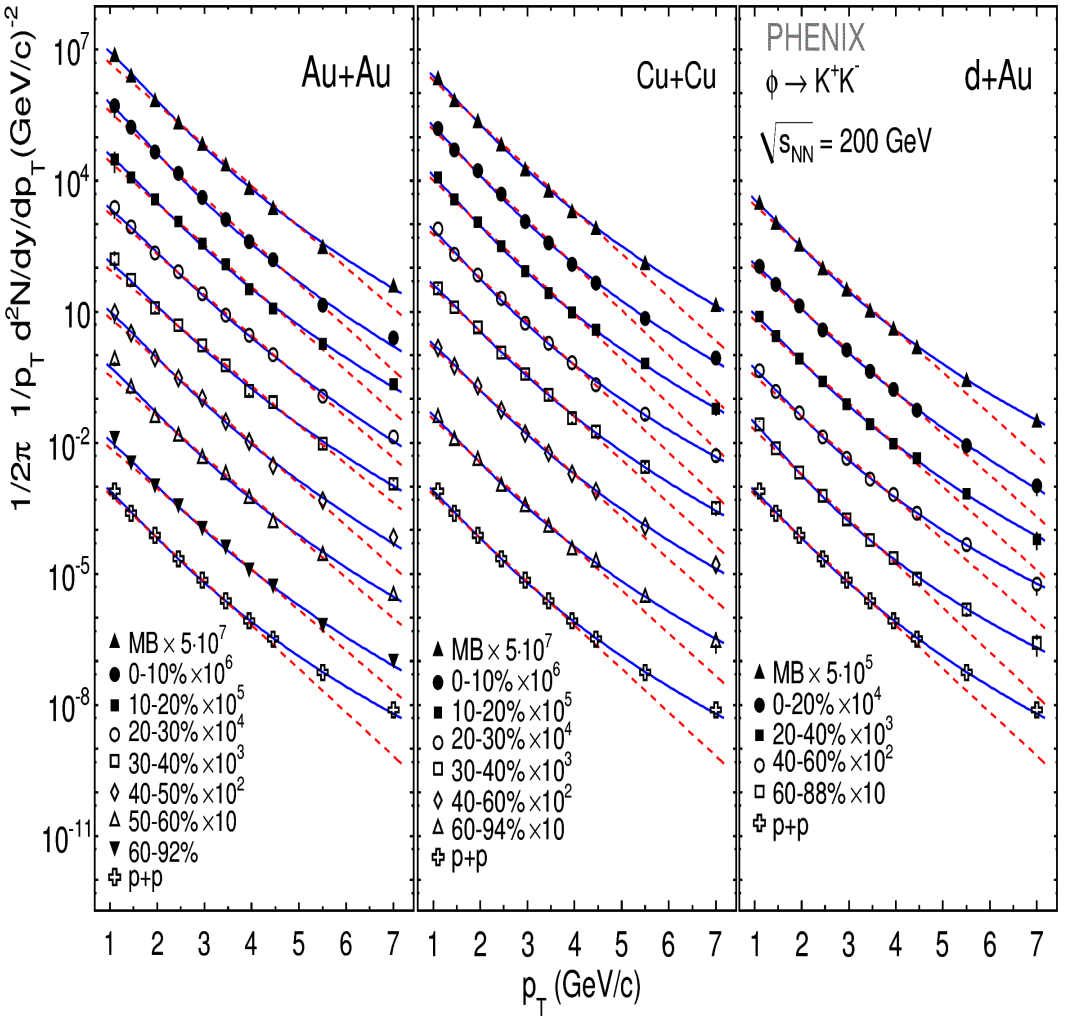
$0.78\times10^9$ *minb Cu+Cu evts*

Phys. Rev. C83 , 024909 (2011)

$1.69\times10^9$ *minb d+Au evts*

$1.5\times10^9$ *minb p+p evts*

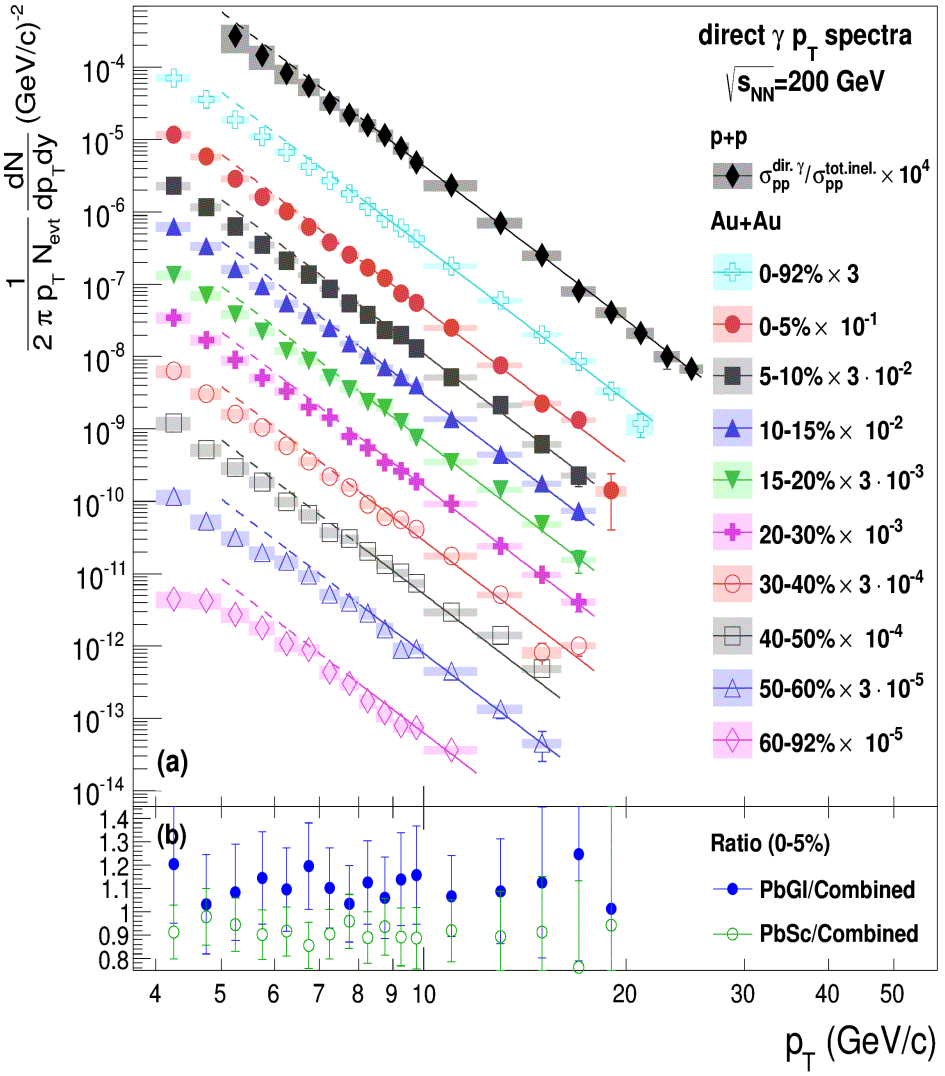



The spectra are fitted to exponential (dashed) and Tsallis functions (solid)

# Invariant direct photon spectra in Au+Au and p+p collisions at 200 GeV

$1.03\times10^{9}$ *minimum bias events* Phys. Rev. Lett. 109, 152302 (2012)




Fit to $\left(A/p_T\right)^n$ *for* $p_T>8\,GeV/C$

$n=7.08\pm0.09\pm0.1$ *for* $p+p$

$n=7.18\pm0.14\pm0.06$ *for* $Au+Au\left(0-5\%\right)$

$n=6.85\pm0.07\pm0.02$ *for* $Au+Au$ *MinB*